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14. ABSTRACT A system to rapidly and automatically assess the performance of numerical ocean modeling systems was developed by the U.S. Naval Research Laboratory (NRL). This includes the calculation of quantitative, objective metrics of the accuracy of ocean forecasts. We will present results from this system, including metrics of surface and subsurface analysis and forecast fields. This work supports the U.S. Naval Oceanographic Office (NAVOCEANO), which provides oceanographic products in response to requests for environmental support for Navy operations. The development of a comprehensive automated system that provides model performance information is expected to increase the consistency of results, reduce errors, and reduce time required to generate oceanographic products.					
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Development of a Relocatable Coastal Forecast System for the US Navy

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Abstract - The goal is to fulfill the US Navy's need for a relocatable, robust operational coastal forecast system by developing and transitioning a high-resolution, coastal circulation model into the Naval Oceanographic Office's operational environment. The coastal circulation model undergoing transition is a three-dimensional, finite-element based hydrodynamic model, the Advanced Circulation Model for Shelves, Coastal Seas, and Estuaries (ADCIRC). Its unstructured grid allows modeling complex coastal regions at fine spatial scale. Scripts and programs are developed to automate major tasks of the forecast run stream such as initial setup, forcing data acquisition, model configuration and post-processing. An application of the ADCIRC-based forecast system to the Korean West Coast region is presented.

I. INTRODUCTION

Navy activities are global, typically in non-US and denied waters; operators have limited time to set-up and configure models and make predictions to support missions. It is critical to develop a modeling system that can be configured quickly, and then perform model simulations and predictions automatically with minimal human intervention. The goal is to fulfill the US Navy's need for a relocatable, robust operational coastal modeling system by developing and transitioning a high-resolution, coastal circulation model into the Naval Oceanographic Office's (NAVO) operational environment.

A relocatable system simply means a system can be moved to different geographic regions or scales easily, with minimal changes in domain configuration. NRL has developed relocatable systems for ocean models (RELO-NCOM) [1] and tide models (PCTides) [2] in the past few years. As the Navy increases operations in coastal, estuarine and shallow regions, a relocatable coastal modeling system is needed (RELO-ADCIRC) that has the capability to make accurate water level and current predictions in complex coastal regions. Two major challenges in developing such system are open boundary specification and grid generation for models based on unstructured grids. The grids for several strategic geographic regions are generated in advance and stored in a grid database. An automated grid generation tool, MeshGUI [3], is also supported for areas not yet available in the database. For the surface forcing, meteorological wind and

atmospheric pressure fields are provided by the Navy Coupled Ocean Atmospheric Mesoscale Prediction System (COAMPS) [4]. Scripting programs are used to integrate individual modeling components and to automate tasks such as creating and configuring model input files, acquiring surface atmospheric forcing data and open boundary tidal information, checking model run status, reporting, post-processing and mapping final products. This article describes the model configuration, grid generation tools, automated scripting, and an example application of the system.

II. ADCIRC MODEL

The core coastal circulation model used in the forecast modeling system is a three-dimensional, high-resolution, finite-element based hydrodynamic model, ADvanced CIRCulation Model (ADCIRC). Its unstructured grid system allows modeling complex coastal regions at fine spatial scale. With properly specified topography/bathymetry, meteorological forcing, tidal potential and boundary forcing, this model can accurately simulate water levels, currents and area of inundation due to wind, tides or other forcing.

Major improvements have been made since the ADCIRC model first developed in the early nineties. The once separated 2D and 3D versions of the code, are now contained within a single unified program. The code has been translated into the FORTRAN 90 language standard and is completely parallelized using the MPI protocol and *metis* domain decomposition software. The code structure itself is modular with individual subroutines containing global dimensioning, cold and hotstart initialization, parameter specification, wind forcing, harmonic analysis, three-dimensional calculations, and the main time stepping loop. Furthermore, the code has become multi-algorithmic with options for selecting various implementations of the conservative or non-conservative Generalized Wave Continuity Equation (GWCE) and/or momentum equation formulations. One notable addition to the ADCIRC v45.11 model code is an improved wetting and drying algorithm. This implemented wetting/drying capability has significantly improved realism, performance and stability of the model when wetting/drying and inundation are important.

A complete description of the theoretical basis for ADCIRC is given by [5, 6] which is found online with the User's manual at http://www.adcirc.org/document/ADCIRC_title_page.html. A comprehensive validation of the 2D and 3D model response under meteorological forcing, tides and inundation for various geographic regions can be found in the newly released NRL Validation Test Report [7].

III. GRID DATABASE

The system uses a database concept to make available pre-existing unstructured meshes for the ADCIRC numerical model. One of the main features of the ADCIRC model is its ability to apply spatially varying, high resolution finite element grids to represent complex coastal regions. As a

result, additional effort is needed to create, edit and refine the triangular meshes when compared with traditional finite difference-based gridding systems. In the database approach used for this system, grids for several strategic regions for the Navy, including the West Korean Coast have been created, and stored in the database. An NRL in-house developed mesh generation and editing tool with Graphical User Interface (GUI), MeshGUI, is included in the system in case users require the creation of meshes for areas not yet available in the existing grid database.

IV. SYSTEM SOFTWARE DEVELOPMENT

One of the major requirements in developing an operational modeling system is to automate routine tasks as much as possible while still maintaining system flexibility and allowing manual override. To meet this requirement, a software program is needed to integrate individual modeling components and to automate tasks such as configuring model input files, acquiring surface wind forcing data and open boundary tidal information, checking model run status, reporting, post-processing and mapping final products. The software developed in support of system automation includes a collection of shell scripts, awk scripts, Perl programs, C programs, Fortran programs and third-party software. Each program is designed to serve a specific purpose or accomplish a particular task. Figure 1 shows the schematic diagram of this modular system.

All the programs and scripts are grouped into five modules according to their functions: 1) System Setup, 2) Data Acquisition, 3) Model Configuration, 4) Model Run Status and 5) Products Generation and Dissemination. All of the scripts and modules are designed to be manually invoked from the command line if errors are found or if a scheduled task is not completed. This feature also allows manual processing to be performed for cases where input files at the time of execution are missing or incomplete. Main functions and programs in each module are described as follows:

Module 1: System Setup

This module contains programs and scripts that setup the operating system's environmental variables, create proper file directory structures, and initialize starting and ending timestamps.

Module 2: Data Acquisition

All the required data for the modeling system are collected and processed in this module. Software used for downloading data from remote servers and reformatting data into ADCIRC-compatible files for model runs, are placed in this module. Required input files for the ADCIRC modeling system include meteorological wind forcing (fort.22), open boundary tidal information (fort.15) and river inflows (fort.20) (currently not used). As an example, the u, v components of wind and pressure fields are extracted from the Western Pacific region (W_PAC) COAMPS standard 27-km data at 3-hour intervals. An option for accepting nested high resolution COAMPS fields (9km or 3km) will be provided. Two interpolation programs are then applied to create spatially and temporally appropriate and continuous high resolution meteorological fields.

Although not currently used, a script is written to allow manual extraction of surface elevation and current components from the Navy Coastal Ocean Model (NCOM) [8] model outputs. Once the unstructured mesh is finalized, locations of mesh nodes along the seaward boundary can be extracted and saved in an ASCII text file that is then used to identify exact locations within the NCOM grid to extract the NCOM parameters of interest for the analysis time and forecasts desired. This can be used to provide surface elevation or normal flux boundary conditions for ADCIRC forcing.

Module 3: Model Configuration

This module consists of programs and shell scripts that create necessary ADCIRC model related input files, fort.14, fort.15, fort.20 and fort.22. In addition, scripts that run the model preparation, execution and post-processing code, *adcrep*, *padcirc* and *adcpst*, respectively, are placed in this module. The four required input files include the fort.14 grid file, the fort.15 model parameter file, the fort.20 flux boundary forcing file, and the fort.22 surface meteorological forcing file are prepared differently as described below:

The grid/bathymetry file is copied from the grid database to the local directory and renamed fort.14 to interface directly with ADCIRC model input file units. Fort.15 is the main model configuration and parameter file. Fixed parameters are save in a template fort.15 file while run specific variables such as starting time, run period or user specified parameters are extracted from Module 1 and appended to the template file. This file needs to be updated for each simulation. Fort.20 is the river inflow forcing but is not currently supported in this implementation of the model forecast system. The fort.22 file is created based the data interpolated from the aggregated COAMPS wind data acquired from Module 2.

Three additional scripts that setup, run and post-process parallel ADCIRC model runs are also included in this module. The *adcrep* program prepares parallel runs, performs domain decomposition, and creates necessary sub-directories based on the user specified number of processors and copies necessary files to proper directories. The model executable, *padcirc*, runs the ADCIRC model as a parallel program using the Message Passing Interface (MPI) software package (OpenMPI). Once model execution is complete, the post-processing program *adcpst*, is executed to put all regionalized output into global files. Default input template files are also written to provide NAVO users additional flexibility to run the model in an automated batch mode or interactively in the case where the hardware platform or the number of processors needs to be changed.

Module 4: Model Run Status

The reason for separating Model Run as an individual module is again to provide NAVO operators additional flexibility. In an operational modeling environment, it is quite common that model configuration, data acquisition and model simulations are all done on different hardware

platforms, for example, configuring model parameter files on a PC desktop, processing model input data streams on a Linux workstation while running the code on a supercomputer or parallel clusters.

Module 5: Product Generation and Dissemination

This module contains software and scripts used to generate, disseminate and archive map products and model outputs. The product mapping scripts invoke appropriate programs and mapping routines based on users' preferences of mapping tools such as the Generic Mapping Tools (GMT), MATLAB or IDL. Mapped products will then be placed on a designated web server for the end users. The planned products include graphical maps of forecast wind fields (speed and directions), water elevations in color contours and currents with arrows showing directions and color indicating magnitudes. Time series of water levels and currents at specific locations will also be included in the products suite. Statistical metrics such as root mean square error (RSME), mean absolute error (MAE) and standard deviation (SD) will be computed based on the user's specification.

V. APPLICATION: WEST KOREAN COAST

An application of the developed forecast system to the West Korean Coast is used to demonstrate the automated and operational capabilities of the modeling system. The West Korea Coast is a highly dynamic tidally-driven region with complex coastlines and tidal flat zones; it is therefore a perfect testbed for a high resolution system that has the capability to model complex geometry and wet/dry situations.

The grid bathymetry was derived from the Naval Research Laboratory Global Digital Bathymetry Data Base (DBDB2) 2-minute resolution dataset (http://www7320.nrlssc.navy.mil/DBDB2_WWW). This dataset also incorporates the high resolution Yellow Sea/Korean Coast data from Choi [9]. The model grid domain encompasses Yellow Sea, Bohai Sea and part of East China Sea where the open ocean boundary follows the 200 m isobaths between Taiwan and Japan [10]. The tidal potential and tidal constituents are extracted from the FEM99 global tidal database [11, 12] and the present setup includes eight main tidal constituents (Q1, O1, K1, N2, M2, S2 and P1). The default setting in the model configuration is to make 48-hour forecasts. The default initialization time is based on the system clock time and the command can be placed in *crontab* utility for routine scheduled daily execution.

When the system is fully tested and ready for operational implementation, a high resolution grid system (290,891 nodes with 88 m resolution) will replace the medium grid. To evaluate the system robustness and reduce the simulation time during the developing and testing stage, a medium resolution grid (10,813 nodes with highest resolution at 420 m) is used. Figure 2 shows

the Yellow Sea regional grid that is being tested now.

VI. SUMMARY AND FUTURE ENHANCEMENTS

The framework of a relocatable forecast system RELO-ADCIRC and an application of the West Korean Coast are being developed. The system consists of numerous Fortran, C programs and C shell, awk and Perl scripts that are categorized into five modules according to their task and functions. At the time of this writing, Module 3 and 4 (core modeling components) are complete and under testing while Module 1, 2 and 5 are under development. It is anticipated that the whole system will be complete within three months' time frame and an additional six months will be used to evaluate model performance in two regions specified by NAVO.

Future enhancements of the modeling system include:

- 1) Continued population the unstructured grid database for Navy geographic regions of interest.
- 2) Extraction of tidal constituents at the open ocean boundary condition using the Oregon Tide Inversion Software (OTIS) [13].
- 3) Integration of boundary forcing from regional scale NCOM domains for improved nesting/coupling.
- 4) Incorporation of a river database to account for the time-varying river influx to improve predictions in estuarine regions.
- 5) Upgrade the ADCIRC code to include its fully 3D baroclinic capability with NetCDF format input/output support.
- 6) Explore the potential of deriving bathymetry/topographic data from a remote-sensing platform such as Shuttle Radar Topography Mission (SRTM), for rapid grid/mesh generation.

REFERENCES

- [1] Rowley, C., P.J. Martin and J.A. Cummings, "The Naval Research Laboratory Relocatable Nowcast/Forecast System," ONR J. of Underwater Acoustics, 2009.
- [2] Posey P.G., R.A. Allard, R.H. Preller and G.M. Dawson, "Validation of the Global Relocatable Tide/Surge Model PCTides", J. of Atmos. and Oceanic Tech., pp.755-775, 2008.
- [3] Blain C.A., R.S. Linzell and T.C. Massey, "MeshGUI: A Mesh Generation and Editing Toolset for the ADCIRC model," NRL Memorandum Report NRL/MR/7322-08-9083, 49pp, 2008.
- [4] Hodur, R., "The Naval Research Laboratory Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)," Mon. Wea. Rev., 125, 1414-1430, 1997.
- [5] Luetich, R.A. and J.J. Westerink, "Formulation and numerical implementation of the 2D/3D ADCIRC finite element model version 44.XX. Theory Report. [Online] available: <http://www.adcirc.org>, 2004.
- [6] ADCIRC User's Manual v45. [Online]. Available: <http://www.adcirc.org>
- [7] Blain C.A., R.S. Linzell and P. Chu and C.M Massey, "Validation Test Report for the Advanced Circulation Model (ADCIRC) v45.11", NRL Memorandum Report, 2009 (*in press*).

- [8] Martin, P.J., "Description of the Navy Coastal Ocean Model Version 1.0," NRL Report NRL/FR/7322/00/9962, 45pp, 2000.
- [9] Choi, B.H., K.O. Kim, and H.M. Eum, "Digital Bathymetric and Topographic Data for Neighboring Seas of Korea," J. of Korean Soc. Coastal and Ocean Engrs, 14, 41-50, 2002.
- [10] Naimie, C.E., C.A. Blain and D.R. Lynch, "Seasonal Mean Circulation in the Yellow Sea – a Model-generated Climatology", J. of Cont. Shelf Res., pp.668-695, 2001.
- [11] Le Provost, C., M.L. Genco, F. Lyard, P. Vincent and P. Canceil, "Spectroscopy of the World Ocean Tides from a Finite Element Hydrodynamic Model," J. Geophys. Res., 99, 24777-24797, 1994.
- [12] Lefevre, F., F.H. Lyard and C. Le Provost, "FES99: A Global Tide Finite Element Solution Assimilating Tide Gauge and Altimetric Information," J. of Atmospheric and Oceanic Technology, 1345-1355, 2002.
- [13] Egbert G. and S. Erofeeva, "Efficient Inverse Modeling on Barotropic Ocean Tides," J. of Atmos. and Ocean Tech. 19, pp.183-204, 2002.

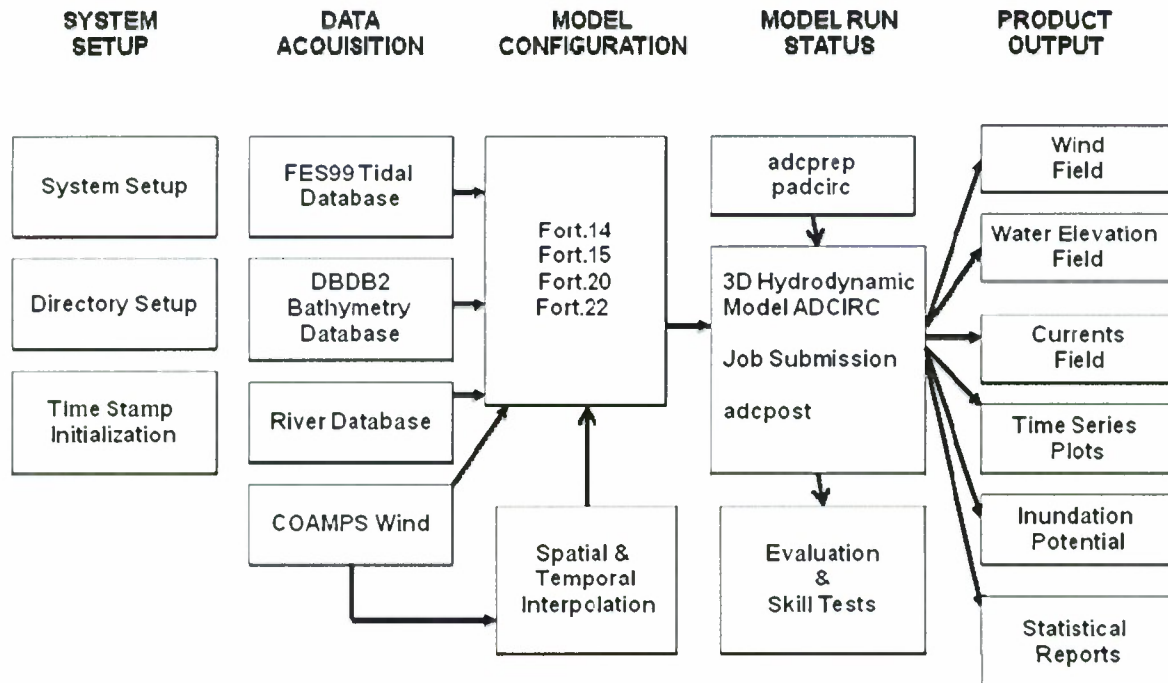


Figure 1. Schematic diagram of RELO-ADCIRC system

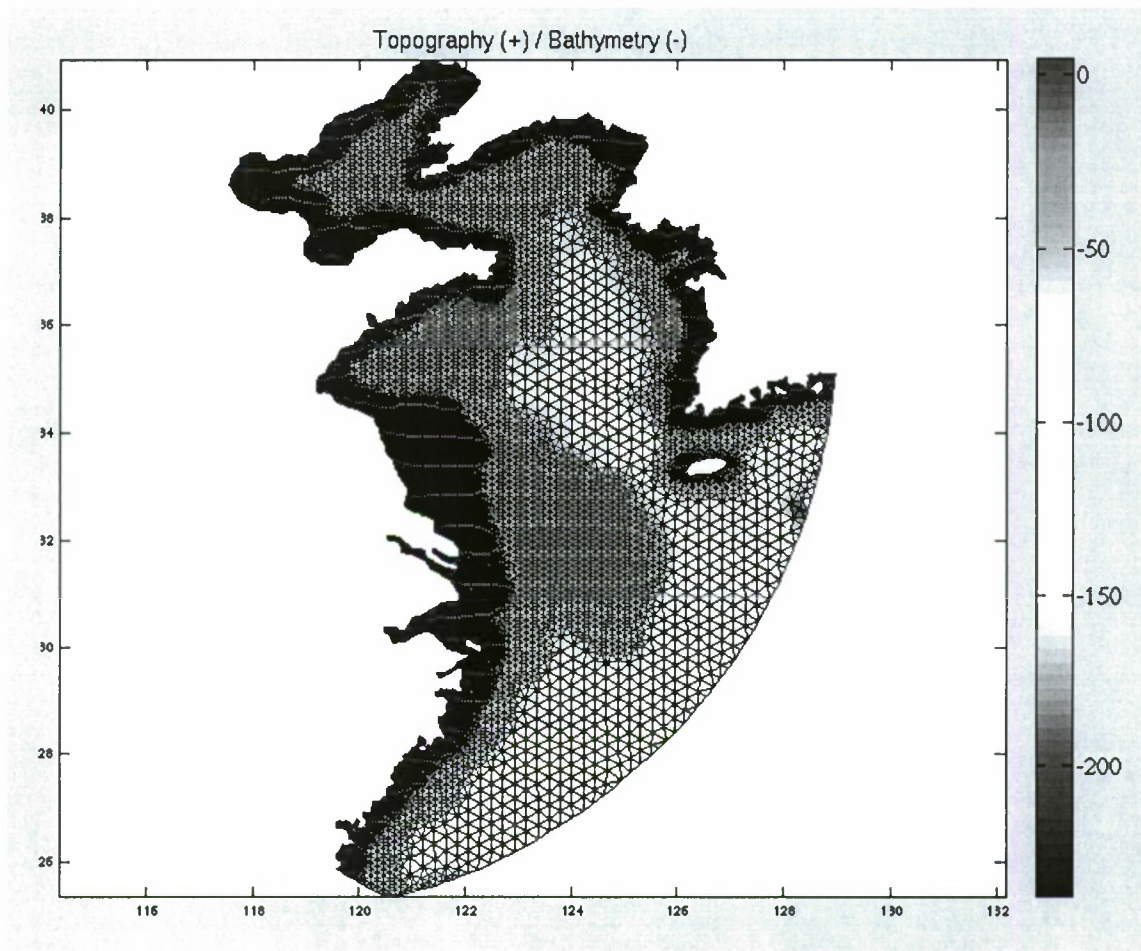


Figure 2. Yellow Sea/Korean Coast grid with bathymetry